International Electrotechnical Commission
Technical Committee 77 - Electromagnetic Compatibility
Subcommittee 77B - High-Frequency Phenomena

Contribution to: Joint Working Group "Surge Overvoltages and Surge Protection"
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Overvoltage protection: Principles, postulates and perceptions

1. Rationale

As our Joint Working Group begins its assigned task, it seems appropriate to take a look at where we are now and where we want to be a few years (not too many!) from now in our knowledge of how to control overvoltages in a safe, technically sound, and cost-effective manner. This paper is being circulated to the Group before the meeting to promote a faster start and quicker consensus building when we meet around the table.

Several of the papers reviewed in an Annotated Bibliography on Cascade Coordination started in 1992 (enclosed) are based on assumed basic parameters that affect the outcome of a coordinated cascade of surge-protective devices (SPDs) in low-voltage end-user systems. Consequently, and it should be no surprise, the conclusions presented by the different authors are sometimes different. Some of these parameters represent a postulate on the environment, over which we have no control. Other parameters result from installation practices over which we have little control, given the existing installations and the present standards that govern them. Finally, even the selection process of SPDs, over which we should have a good measure of control, is in fact uncontrolled in an unregulated marketplace where end-users lack dependable information.

Lest we meet and work to discuss the technical problems and reach contradictory conclusions resulting from different postulates or perceptions, we need to agree on these parameters to carry on a meaningful discussion in our quest for a technically valid solution. Preparing effective recommendations for the control of overvoltages (also known as surge protection, lightning protection, disturbance mitigation, insulation coordination ...) requires judicious application of the fundamental principles known to us and use of available tools, for the ultimate goal of dealing with the reality of overvoltages as they occur in our systems. In recent years, one of the concepts initially proposed by IEC Pub 664, namely the existence of a down-staircase of voltages, has come into question. Work on SPD cascade coordination clearly shows the pitfall of that concept, and research on the propagation of surge *voltages* casts a serious doubt on the likelihood of a natural reduction of *voltage* surge amplitudes as they propagate from the service entrance to the end of the branch circuits.

Our discussions are likely to address four aspects of the problem: what is occurring in the real world; what we can simulate and measure with discrete components in the laboratory; what we can simulate and compute with a numerical model; and finally, what protection industry can provide at a price that end-users are willing to pay. It is not evident that all four aspects use a common foundation of compatible postulates. There seems to be as many unanswered questions as unquestioned answers that might sidetrack us, literally, while our objective should be to go forward (Figure 1).

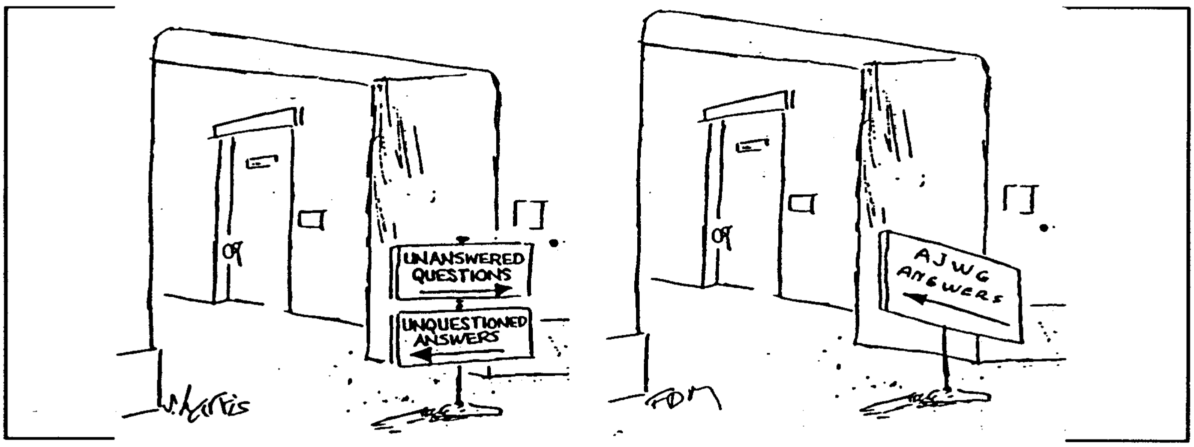

Figure 1 - The choice is ours !

The diversity of our professional and technical experiences is likely to give each of us a different perspective on the technical and economic problem we are attempting to solve. In fact, this diversity will be an asset in our work if we can start by identifying the unanswered questions and, at the outset, reopen the unquestioned answers, treating them all alike.

Therefore, the following questions are proposed for consideration as possible initial topics of consensus-building. Agreeing on perspectives and goals now will avoid misunderstandings later, as well as preventing circular discussions in our work. Some of these questions might seem trivial, or their answers obvious, but raising them in the form of a check list, presented at the end of this paper, might still be useful to focus our discussions. For the sake of starting the review and discussion, the questions are listed according to the four aspects cited in the Rationale above. This organization may readily be modified as the AJWG contributors might propose other structures and identify important questions that may have been overlooked in the present paper.

2. What is occurring in the real world ?

We have several sources of information available, as listed below, on what the surge environment is in the real world of low-voltage systems. Other members of the AJWG most probably have other sources known to them, so that pooling these sources may be a task for the AJWG to undertake or to delegate.

2.1 Direct observation of overvoltages

Without going back to Benjamin Franklin's days, many researchers have conducted surveys and measurements to quantify the threat of overvoltages. These have been along two main categories: One is the direct measurement of the phenomenon near its source, such as the lightning stroke (passive monitoring on selected sites, or triggered discharges through an instrumented path), a capacitor switching event, a fuse-blowing occurrence, a contactor bounce, etc. The other category is the monitoring of overvoltages in the end-user system, mostly in low-voltage ac power systems at the point of common coupling or at the point of use. The literature[1] also contains reports of measurements in telephone systems and in medium-voltage ac distribution systems. Progress in instrumentation is remarkable, starting with Liechtenstein figures on film, magnetized link detectors, threshold counters, oscilloscope-camera combinations, and now digitizing instruments with on-board data processing capability and text/graphics output.

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[1] *This paper being a discussion-starter and not an academic-type treatise, no references are listed at this stage. Depending on the wishes of the AJWG, a list of references may be compiled as a joint effort. In the meantime, the absence of references should not be seen as ignoring the many contributors to the field.*

A serious difficulty has surfaced in comparing and consolidating results: each researcher used different criteria or thresholds to define and accept in the data base what is then reported as a significant event. For instance two widely cited surveys, Goldstein & Speranza used for their threshold the values above which telephone equipment might be disrupted, while Allen & Segall used computer disturbance thresholds as their criteria. Another limitation of these monitoring campaigns in end-user systems is that most have been limited to the measurement of a voltage. Very few included a current measurement. This limitation, however, has not stopped some authors from computing the time-integral of the square of the voltage, dividing it by some impedance and calling the result "energy in the surge", offering that result expressed in joules as guidance for the selection of an SPD ! The reality is that a non-linear SPD inserted in the loop formed by the surge source, the transmission line, and the SPD cannot be equated to the linear configuration assumed when computing the energy dissipated in a resistive load. Not knowing the complete circuit parameters, the energy that would be deposited in an SPD connected at the point of measurement cannot be determined from the voltage measurement alone.

There is no agreement, perhaps even little understanding, on how a surge event should be viewed: is it a voltage source that is fed by a transmission line to the equipment, is it a current source, or is it a discrete amount of energy injected into the power system? Depending upon the answer to these questions, different scenarios will be written for describing how a surge of several thousand amperes can propagate through a 277-ohm or 400-ohm "transmission line" insulated for low-voltage characteristics, how the line should be viewed (distributed or lumped elements), and many other questions or apparent contradictions. With more information provided on these assumptions, these apparent contradictions might then be resolved into simple explanations.

Would it be beneficial to the process that the AJWG compile an up-to-date bibliography of the many published surveys, and attempt to secure advance information on those surveys currently in progress here and there? Is such an undertaking already in progress somewhere in the IEC or in some other organization?

2.2 Theoretical analyses

Physicists have conducted analyses of the lightning discharge phenomenon, engineers have computed the parameters of switching surges, all in an effort to predict and quantify the result of a phenomenon which cannot be readily duplicated in the laboratory. In some instances, however, it has been possible to conduct some experimental work in conjunction with the theoretical analysis and thus to validate the process.

2.3 Using field failures as a monitor of overvoltages

Manufacturers typically are reluctant to give broad publicity to the failure of their products, and most field failures are reported by users or their consultants. This situation is not ideal as some bias may occur in the process. This is unfortunate, as field experience is the ultimate validation of all theories and design, and very convincing evidence could be gathered through this channel. Examples of such data include: a case history of clock redesign to 6 kV withstand following widespread failure for a 2 kV withstand, producing a 100:1 reduction in the failure rate; the fact that most 120-V rated incandescent light bulbs flashover and burn their filament with surges above 1.5 kV but still achieve an acceptable life in use; the fact that millions of varistors installed in equipment do not fail in the field but fail in the laboratory when exposed to a long-duration surge proposed in the IEC Standard 1000-4-1 menu.

2.4 Agreeing on a limited set of parameters

Here again, a pooling of such field experience among the members of the AJWG would be a strong factor toward building credibility for proposed "representative waveforms" that SPDs should be capable of dealing with. There is a tendency among standards writers to specify test waveforms that duplicate as closely as possible what is happening in the real world, a commendable goal, but resulting in a proliferation of "standard waveforms". In a 1987 paper, Frey tabulated 95 (ninety-five !) *standards* [2] calling for

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[2] *One common would-be humorous poster found in metrology laboratories states: "The nice thing about standards is that there are so many of them, that you can choose the one that best suits you !"*
Actually, this is a rather dark and sad commentary on the state of international and national standards .

"representative waveforms". Thus, one of the first tasks of the AJWG is likely to be the challenge of achieving a consensus on what parameters (waveform, amplitude, source impedance, frequency or probability of occurrence ...) should be considered in our work.

3. What can we simulate and measure with discrete components in the laboratory ?

Laboratory work on surge protective devices and protection of equipment is generally conducted on full-scale equipment if possible, or on sub-assemblies if the full-scale is impractical. The surge is obtained from home-made or commercial generators. The goal is sometimes perceived as a demonstration that the equipment will be immune to real-world threats. Actually, and this may sound trivial or obvious but is often forgotten: all the test has demonstrated is that the equipment has survived the test. An important aspect of that procedure is to ensure that comparisons can be made within one laboratory between tests performed on different designs or at different times, and that comparisons among laboratories are meaningful. This fact alone is sufficient to demand agreement on standard procedures and standard surges. Some occurrences have been noted that test generators built by different organizations, each in accordance with the specifications of a particular standard, may in fact produce different stresses. Careful standards writers address that problem through systematic round-robin test programs. Researchers attempt to prevent the problem by inviting peers to corroborate their results. Thus, one task of our coordination working group may be to catalyze such round-robin tests and corroboration of results.

The type of surge generator used in different laboratories, or among different groups of users, is also a subject that our AJWG should consider. The question surfaced during the Florence meeting of two years ago, even though the agenda did not allow for in-depth discussion. Depending upon the assumptions made on the real-world threat, the surge generator may be viewed as a voltage source, a current source, or a hybrid source.

From years of testing for insulation withstand, many laboratories have developed the mental habit of testing with voltage waveforms, without much concern about the impedance of the generator as long as the specified voltage could be maintained across the test piece. Surge arrester people, on the other hand, were equally concerned with the response of an arrester to a voltage front and to a discharge current, but they generally separated the two aspects in different tests. Low-voltage electronics users and manufacturers developed the concept of a hybrid generator to test the response of a given equipment to its environment.

One result of bringing these different points of view to the same laboratory is the attempt to modify a surge generator designed for one assumption so that it can also be used to perform a test for another set of assumptions. For instance, a generally accepted internal impedance value for a hybrid (a.k.a. Combination Wave) generator is 2 ohms. Other suggested values have been 10 or 12 ohms, 50 ohms, 400 ohms... The next thing that happens is that an external resistor is being inserted in the test circuit, losing sight of the fact that the "2 ohms" is in fact the ratio of the peak open-circuit voltage and peak short-circuit current (which occur neither concurrently -- they are mutually exclusive -- nor at the same time of the event), and while it might have the dimension of ohms, calling it internal impedance is an oversimplification; a reminder would be to call it `effective impedance'.

Measurements made with modern instruments pose few problems. Industrial laboratories are staffed with competent personnel and few artifacts escape detection. In fact, producing test records has become so easy that one can be easily drowned in test data. A challenge is then to unify laboratory results and the conclusions that can be drawn from the overabundance of laboratory data. This challenge may be beyond the scope or capability of the resources available to the AJWG members, but it is worth noting.

4. What can we simulate and compute with a numerical model ?

Numerical modeling has gained popularity as software packages have become readily available, supplementing the analyses initially limited to main-frame computers, including classical codes such as EMTP. However, the very availability of many computer programs has produced a flurry of studies which are not readily comparable. For instance, Martzloff persuaded different experts on computing methods to contribute to several surge-related investigations: given the freedom to do so, each computing expert chose a different model to simulate the source of the surge, its propagation in the circuit, and the response of the circuit or device under test. Is such a diversity useful in demonstrating the flexibility of the approach, or is it counterproductive by making comparisons among experts more difficult? Should the AJWG promote the use of a particular code, without falling into the trap of restricting the freedom of researchers?

In these investigations, reasonable agreement has been found between experimental and modeling results when both were conducted, but some discomfort lingers about the need and justification of applying scarce resources to recreate a model for each investigation. Another lingering discomfort when attempting a computer modeling project is rooted in the simplifications that must be made to the equivalent circuit so that the program can be handled by the computer. Members of the AJWG with more experience on modeling techniques, or access to modeling/computing experts might consider some work aimed at catalyzing the use of only a few, well recognized and user-friendly computer codes. The quest for improvements and originality so inherent in motivated researchers should be balanced against the desirable cost-effectiveness and easier consensus obtained with stable, well-accepted modeling methods.

5. What can industry provide at a price that end-users are willing to pay ?

Under development - major themes:

- statistical aspects of threat
- statistical aspects of equipment withstand
- classification of environment/users
- type of mission (consequences of failures)

6. Quo vadis ?

The final question raised in this position paper is meant as a gentle reminder to the AJWG. We should structure our work, discussions, and ultimately preparation of useful documents based on a pragmatic recognition that while an ideal situation may be designed and even proposed as a mandatory standard, acceptance of such recommendations by industry is the ultimate criterion of a successful undertaking. We should not indulge in a quest for perfection, but seek out solutions that can be implemented in the short term, perhaps with some directions given for the long term if they have a reasonable likelihood of acceptance. Hopefully, this position paper might help toward that objective.

CHECK LIST

What is occurring in the real world ?

- What information does each member of the AJWG have on surge occurrences?
- Should the AJWG prepare a (annotated) bibliography?
  - For its own use in developing documents
  - As a service to other IEC groups
- Can the AJWG propose a generally acceptable, limited set of threats?
  - Lightning
  - Normal switching operations
  - Fault clearing
  - Others
- Other questions from the AJWG:
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What can we simulate and measure with discrete components in the laboratory ?

- Select a current, voltage, or hybrid source, according to the origin of the threat?
- Is there agreement on waveforms?
- Other questions from the AJWG:
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What can we simulate and compute with a numerical model ?

- What models are available for a varistor?
- What models are available for a gap?
- What models are available for the threat source?
- What model should be selected for the wiring system?
- Is there a preferred approach to be recommended to others?
- Other questions from the AJWG:
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What can industry provide at a price that end-users are willing to pay ?

- Statistical aspects of the threat
- Statistical aspects of equipment withstand
- Classification of environment/users/locations
- Type of mission (consequences of failures)
- Other questions from the AJWG:
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Quo vadis ?